2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

IMAGE-BASED SITE-SPECIFIC PLANT GROWTH REGULATOR (SSPGR) APPLICATIONS AT PERTHSHIRE FARMS

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Abstract

Plant Growth Regulator (PGR) in cotton traditionally has been applied in a blanket fashion. Vegetation indices generated from remotely sensed imagery can aid in creating site-specific prescriptions for the application of PGR. Plant height, length of the top 5 nodes, and 4th internode length have been used to generated PGR rate recommendations. If there are correlations between these plant measurements and vegetation indices, then the vegetation indices may be used to drive rate recommendations. A randomized block experiment is performed to test the differences in crop canopy and yield associated with site-specific, variable-rate and blanket applications of PGR. An economic analysis is performed to compare the cost structures of the site-specific and variable-rate PGR applications with the traditional blanket PGR application techniques.

Introduction

Plant Growth Regulator (PGR) is used for cotton plant management. When applied to the crop, it redirects plant growth from the vegetative leaves to boll production and as a result can increase yield. In the 2001 growing season an experiment was performed to study the effect of PGR application across different Normalized Difference Vegetation Index (NDVI) regions of a field. NDVI measurements were extracted from remotely sensed data acquired over the field. The research field was segmented into three types of treatment strips. One type received blanket applications of PGR according to traditional methods. The other treatment strips received no PGR. The third received Site-Specific PGR (SSPGR) applications. The SSPGR treatments had zones defined by NDVI that received either an "on" or "off" application of PGR. The treatment strips were crossed with the three different NDVI groupings to determine if plants with different NDVI measurements respond differently to PGR.

Results of the 2001 research indicated that there may be economic benefit in using site-specific and/or variable rate application techniques to apply PGR on cotton fields. Variable Rate PGR (VRPGR) application varies the PGR spatially according to NDVI regions. VRPGR applications are more complicated than the SSPGR applications because in addition to turning the spray nozzles "on" and "off", the process calls for varying the amount of chemical. The SSPGR application uses one set amount of chemical for the "on" rate. This year's experiment replicated the design of last year's study. In addition, VRPGR treatment strips were established to study variable rate applications of PGR. Also, correlations between plant measurement and vegetation indices were performed to determine if vegetation indices can be used to estimate PGR rates. The intent of the study was to determine if SSPGR and/or VRPGR application methods can be used as techniques to reduce PGR application costs and at the same time maintain or increase yields over the traditional (blanket) method of applying PGR. The height of the plant were also measured to determine if SSPGR and/or VRPGR application methods manage the plant canopy as well as the traditional blanket applications of PGR. Good management of the plant canopy allows for the spray rig to have unrestricted access to the crop.

Background

PGR, in this case Pix Plus® (Mepiquat Chloride), is applied to inhibit cell elongation, to restrict vegetative growth and to promote earlier and heavier boll production on lower node branches and thus increase lint yield (Weir and Kerby, 1988). It is usually applied in a blanket fashion based on factors such as height, height-to-node-ratio, average length of top five internodes, internode length, and moisture status (Kerby et al., 1990). Plant height is widely recognized as a strong indicator for PGR application, by Weir and Kerby (1988), Kerby et al. (1990) and Munier et al. (1993), who showed that plant height was "related to plant vigor and early fruit retention and this is a good indicator of the need for Pix Plus®." Kerby et al. (1990) cited plant height prior to first bloom as the premier of six indicators for triggering PGR application. These factors are commonly checked in the field by consultants, sometimes aided by Geo Positioning Systems (GPS) (Thurman and Heiniger, 1998). Kerby (1985) observed yield benefits in the use of PGR, and Cothren and Oosterhuis (1993) found that the maintenance of a uniform cotton crop benefits insect management, crop termination, and harvest. However, blanket applications of PGR at a constant rate sometimes expend the chemical needlessly in areas where they are not needed and may decrease yield in these areas by repressing the growth of weaker or slower maturing cotton. Likewise, insufficient application may decrease yield in robust, excessively leafy areas.

In 1998-1999, ITD measured yield corresponding to five levels of NDVI during 23 image dates in two different fields. NDVI patterns from the fields studied in 1998 and 1999 showed empirical evidence that the highest 20 percent of NDVI areas became increasingly indicative of lower-yielding areas as the season progressed, indicating that these areas may be ideal candidates for site-specific PGR application. These observations resulted in a more formal PGR experiment at Perthshire Farms in 2000.

The 2000 experiment partitioned a cotton field into two different types of treatment strips that represented different application rates of PGR. One treatment area received blanket applications of PGR and was labeled as Blanket-Spray-On treatments. The other treatment area was not sprayed with any PGR and labeled as Spray-Off treatments. NDVI measurements were computed for the entire field during the season. In addition to the partitioning by PGR application type, the field was also partitioned by equal area NDVI values taken from the 07/05/2000 data set, which was just prior to the first PGR application in 2000. Equal area partitioning establishes regions of differing NDVI values in the field such that each region has the same number of data elements. The 2000 NDVI classification segmented the field into five equal area NDVI regions. The middle three regions were aggregated into one larger region, thus creating three NDVI groups: the highest 20%, the middle 60% and the lowest 20% NDVI measurement. There were statistical differences in the yields within the treatment/NDVI regions. This motivated a spatially variable or site-specific Plant Growth Regulator (SSPGR) experiment to be designed for the 2001 growing-season.

ITD reviewed many papers that discussed variable rate applications of PGR, including Weir and Kerby (1988), Munier et al. (1993) and Thurman and Heiniger (1998). Most had generally positive results with the potential of minimizing the use of the chemical and maintaining or increasing yield. Other research explored adjustments in the timing and quantity of PGR applications. However, we have not found any specific references to the use of imagery for site-specific PGR application in cotton. Thurman and Heiniger (1998) briefly mentioned the use of aerial photographs “to assist in identifying areas of the field which differed in growth and development” in the context of a PGR study, but the photos were not directly germane to the study. Thurman and Heiniger did, however, determine (through grid-based field samples) that the variability in key cotton indicators was “wide enough to justify VRT practices and application of Pix®. Spatial analysis would improve the decision process of PGR application timing.” Thurman and Heiniger (1999) identified growth areas and soil types in fields using aerial photography, GPS scouting, digital soil surveys and field histories. They also demonstrated that height control in rapid growth situations is critical to high boll retention and yield in cotton fields. Coupled with the previous ITD investigations, this research points to the use of imagery to identify vigorous areas, which are likely to exhibit excessive plant height, and thus may serve as a sound basis for a spatially variable PGR application. NDVI change maps may complement NDVI maps in locating the “rapid growth areas”.

Last year’s experiment tested two separate concepts simultaneously in a factorial design: (1) the impact of plant-growth regulator (PGR) application on yield when applied to high, medium, and low NDVI regions, and (2) the impact of SSPGR applications on yield. As in past years, last year’s study generated NDVI segmentation by breaking the NDVI image into the lowest 20%, middle 60% and highest 20% equal area groupings. The imagery was calibrated allowing NDVI values from one date to be directly compared to other dates. Calibration compensates for in-season differences in atmospheric effects and radiometric differences and allows for the creation of NDVI change maps in addition to NDVI maps. The NDVI and NDVI change maps were broken into equal area classes and downloaded onto IPAQ handheld computers so that the field scouts could navigate to the different NDVI and NDVI change zones within the field. Using measurements collected at different locations in the fields, the scouts made PGR rate recommendations. Since some zones received no PGR, the amount of chemical was reduced. By reducing the amount of chemical applied in the field, significant savings in cost for PGR application were achieved.

This year’s experiment refined last year’s design. The three basic treatment strip types remained; the 100% spray treatment strip (“on”), the 0% spray treatment strip (“off”) and the site-specific treatment strip (“on/off” determined by imagery). A variable rate treatment strip that used three different rates of PGR across the field was added to the design. Vegetation index values generated from imagery were used to determine the variable rate zones. Correlation between vegetation indices and plant measurements were computed. Plant measurements were estimated using vegetation indices. These estimations were used in conjunction with standard Pix Sticks to generate rate recommendations. These rate recommendations were divided into an “on” and “off” grouping for the site-specific treatment strips and were divided into three groupings for the variable rate treatment strips. The yields from the treatment strips were analyzed to determine statistical differences between the yields of these 4 types of PGR treatment. In addition to the yield analysis, plant height measurements were performed. The variance in the plant height for each treatment was analyzed to determine how the image based PGR applications manage plant canopy when compared to the traditional blanket PGR application.

Project Goal

One goal of this study was to correlate remotely sensed image data to specific plant characteristics indicative of plant vigor that are normally sampled when scouting for PGR applications. This study investigated the ability of reducing chemical input of PGR while maintaining or exceeding yields of normal 100% PGR application through site-specific and variable rate applications based on imagery. Plant canopy management is an important reason for PGR application. An additional goal of this study was to show that image based PGR applications can effectively manage plant canopies.

Study Area

The study area was a 30.4 hectare (75 acre) section out of a 51 hectare (126 acre) cotton field identified as T167-18 at Perthshire Farms near Gunnison, Mississippi (Figure 1). This field was used in the PGR experiment last year.

Hypothesis

An analysis was conducted to determine the significant differences between the yield of the 0%, 100%, Site-Specific (SSPGR) and Variable Rate (VRPGR) spray areas.

1) Significant relationships, using an alpha of 0.1, exist between image reflectance and one or more plant parameters tested.

H_O: There are no significant relationships between image reflectance and any plant parameters tested.

H_A: There is a significant relationship between image reflectance and one or more plant parameters tested.

2) Ho: There are no significant differences in net profit to the producer between the treatments.

$\text{Net Profit}_{\text{SSPGR areas}} = \text{Net Profit}_{\text{VRPGR areas}} = \text{Net Profit}_{\text{0\% spray areas}} = \text{Net Profit}_{\text{100\% spray areas}}$

Where Net Profit = Crop Revenues – PGR Input Costs

H_A: At least one treatment mean is significantly different.

If the analysis fails to reject Ho, then it indicates that there is no economic advantage to using image-based application of PGR as opposed to the traditional 100% application to a field.

If Ho is rejected, and $\text{Net Profit}_{\text{SSPGR, VRPGR areas}} > \text{Net Profit}_{\text{100\% spray areas}}$ then the analysis shows that SSPGR and/or VRPGR applications increases a producer's net profit.

3) Ho: There are no significant differences in plant height variance between the treatments.

$\text{Plant height variance}_{\text{SSPGR areas}} = \text{Plant height variance}_{\text{VRPGR areas}} =$
$\text{Plant height variance}_{\text{0\% spray areas}} = \text{Plant height variance}_{\text{100\% spray areas}}$

H_A: At least one treatment mean is statistically different.

If the analysis fails to reject Ho, then it indicates that SSPGR and VRPGR as well as the traditional blanket method maintain crop canopy uniformity.

If Ho is rejected, and $\text{Plant height variance}_{\text{SSPGR, VRPGR areas}} < \text{Plant height variance}_{\text{100\% spray areas}}$ then the analysis shows that SSPGR and/or VRPGR may help increase crop canopy maintenance.

Experimental Design

This experiment used a randomized complete block design (Figure 2). The design allowed for testing of the underlying concept that image-based applications of PGR can increase net profit to a producer through a reduction in applied chemical and maintenance or increase in yield from the traditional method. It also allows for testing the concept that image-based precision application methods of PGR can maintain or increase crop canopy management.

The 2002 treatments were as follows:

Treatment A: 0% PGR application (OPGR)
Treatment B: 100% PGR application :traditional method (100PGR)
Treatment C: Site-Specific PGR application (SSPGR)
Treatment D: Variable Rate PGR application (VRPGR)

The cotton rows were 1.016 meters (40 inches) wide. Treatments were applied to strips that were 24 rows wide and approximately 800 meters in length. The four treatments were replicated 4 times. The PGR application rates in the SSPGR and VRPGR were driven by vegetation indices created from remotely sensed data, and the correlations that the image data had with plant parameters. The plant parameters were collected weekly at 7 sample sites across each of the treatment strips. Image data was collected weekly by an airborne RDACS sensor. Plant measurement to imagery correlations and communications with the producer team were used to establish thresholds in the imagery that determined the SSPGR and VRPGR application rates. The PGR chemical used in the experiment was Pix Plus® produced by BASF.

Imagery and Field Data Specifications

Image Data
This experiment relied upon data from the RDACS three-band (540nm, 695nm, 840nm, +-5 nm) multispectral sensor. The sensor flew in an airborne platform at 1829 meters (6000 feet) in order to collect data at a 1-meter resolution. Imagery was collected through June, July, and August. Vegetation index products were generated from the reflectance bands of the RDACS sensor.

Field Data
The experiment field was visited by a field scout to determine the optimal PGR application timing. The field scout also made PGR rate recommendations for the 100PGR treatment strips.

Plant parameters were measured in the treatment strips to establish a database for correlations to imagery. These plant characteristics also helped the analysis of the crop canopy management. These measurements included plant height, plant density, length of the top five nodes, the distance between the fourth and fifth node and total number of stem nodes. From this data the average internode length of top five internodes was calculated.

Methodology

Image Processing Procedures
The image processing procedures used in the experiment are listed below.

1) Imagery was captured during June, July, and August. The imagery was collected every 7 to 10 days.
2) Bands were band-to-band registered. The RDACS sensor has 3 separate Kodak cameras, each with a filter to allow the energy of the appropriate wavelength to reach its CCD array. As a result, the image frames are not co-registered. The band-to-band registration process was performed to spatially register the bands to each other.
3) Imagery was georeferenced to a combination of Digital Ortho Quarter Quads (1:12,000 National Mapping Accuracy Standard) and GPS reference points. The process used nearest-neighbor resampling and the output data was placed in the Universal Transverse Mercator (UTM) coordinate system with the WGS84 datum. All data and analysis was performed in UTM. However, the final prescriptions were projected to lat/long coordinates to accommodate the applicator software.
4) Radiometric calibration was performed on the imagery. It used pseudo-invariant features that were near the experiment field as reference for the calibration process. These features included asphalt roads, gravel roads and concrete bridges. Spectroradiometer reflectance measurements of the pseudo-invariant features were taken and were used to transform the raw 8-bit Digital Numbers (DNs) to percent reflectance in the imagery. A linear regression was performed between the digital numbers of the pseudo invariant features retrieved from the imagery and the true percent reflectance measurement for each pseudo invariant feature. The linear regression equation was calculated and applied to the imagery to convert the data to percent reflectance.
5) All non-field areas, including field edges and roads among the fields, were masked out of the image scene, leaving only pixels within the experiment field.
6) Vegetation index and vegetation index change maps were generated from the image data.

Field Data Collection
Seven GPS designated sampling points were spaced equally along each strip at the beginning of the season and were revisited at each sampling date. Sampling dates ranged from prior to and following the PGR application. Plant measurements included plant height, plant density, length of the top five nodes, the distance between the fourth and fifth node and total number of stem nodes. The sampling data collected at these points was used to derive the thresholds for the SSPGR and VRPGR treatment strip prescriptions.

Plant characteristics were recorded on the Compaq iPaq handheld computer. Shapefiles containing the sample points were stored onto the iPaq. The shapefiles were updated by selecting the sample point and then entering the plant measurement information. The shapefiles were then downloaded onto a desktop computer for analysis.

Plant measurements were taken roughly once a week beginning at the northwest corner of the field and working down through the treatment strips. There were times that not all 112 sample points could be collected during one week. This occurred because rain events or other farm practices prevented access to the field. When this happened, the measurements that were recorded during the week were packaged into one data set. A new data set beginning at the northwest corner of the field was started the next week.

Statistical Analysis

The PGR rates for the SSPGR and VRPGR treatments were determined by estimating plant physiology from remote sensing. Cotton Growth Regulator Guides ("Pix Sticks") were used in generating rate estimates for these treatments. There are several sources of Pix Sticks, including Deltapine Seed and BASF. The Pix Stick is a chart that uses plant measurements to generate a specific Pix rate recommendation. The Deltapine Seed Pix Stick uses the distance between the fourth and fifth node, the total number of stem nodes and plant height to generate a rate recommendation. The BASF Pix Stick only uses the length of the top 5 nodes as input to generate PGR rate recommendation. Correlations between the imagery and the plant measurements were used together with the Pix Stick to generate the rate recommendation. The treatment's plant height variances were compared to determine statistical difference in canopy management.

Six-row pickers equipped with GPS were used to harvest the cotton. The seed cotton yield of each treatment strip was harvested, weighed, and recorded for data analysis. The yield for the statistical analysis was generated by averaging the yield around each of the sample points in a buffered area 20 meters across the rows and 60 meters along the rows.

The SAS application was used to perform statistical analysis. The analysis included correlations between plant measurements and imagery, difference tests between the yield from the treatments and variance analysis of the plant height of the treatments.

Results

The experiment field was planted with Paymaster 1218 cotton seed on 04/19/02. Because of excess rain and low temperatures, the cotton emergence across the farm was inconsistent. Several fields had areas where the cotton did not emerge. This resulted in significant areas of the farm needing to be replanted. On 05/20/02 roughly one third of the PGR experiment field was replanted with Paymaster 1218 cotton seed. After studying the location of the replant areas, it was determined that the comparison of the treatment strips would be valid and that the experiment would continue on field T167-18.

The experiment plan called for data to be collected every 7 to 10 days. Cloud coverage over Perthshire Farms caused problems in flight planning. The decision of whether or not to perform the data acquisition flight needed to be made on the evening prior to the acquisition date in order to allow for ferry time. During the summer, it wasn't uncommon to have clear skies early in the day, but then convection and humidity would cause cumulus clouds to pop up during the late morning and early afternoon. The critical period of the day for acquisition was usually in the morning before the popcorn cumulus clouds appeared. Therefore, the aircraft needed to leave before 7am to ferry to Perthshire for the acquisition to be performed around 10am. Weather websites and other information sources were monitored on the day before the flight to determine if a successful data acquisition mission could be performed. If all the information sources seemed to indicate favorable weather, a decision to perform the mission was made. Some data acquisitions happen in less than the 7 day interval just to make sure that unexpected cloud coverage didn't prevent timely data collection. Table 1 and Figure 3 show the flight dates and days between flights. The longest interval between acquisitions was the 21 days between the 9th and 10th acquisition. This was the result of a combination of excessive cloud coverage and sensor malfunction between the acquisition dates. On average, there were 8.33 days between flights.

The plant parameter measurements began on 06/09/02 and were taken roughly every week through the end of August. The Deltapine Seed Pix Stick requires 3 plant parameter inputs. Estimating these inputs proved to be complex. The image data was used to estimate the plant height and distance between the fourth and fifth. The farm weather data was used to compute the DD60 measurements. DD60 is a measurement of growing conditions. In general, the DD60 measurement for each day is an average of the minimum and maximum temperature minus 60. The overall DD60 measurement is an accumulation of each day's DD60 measurement since the plant date. The DD60 measurement, irrigation and Veris data were used to estimate the number of stem nodes. Estimating the 3 input parameters for the Deltapine Seed Pix Stick was complicated. The BASF Pix Stick only required the length of the top 5 nodes for input. Therefore, this study used the BASF Pix Stick to help establish PGR rate recommendations. This isn't meant to endorse the BASF Pix Stick over any other Pix Stick. Using the BASF Pix Stick was simply a straightforward method to generate a PGR rate recommendation.

During late June the field scouts were reporting that the first application of PGR across the farm would need to occur soon. Correlations between the 06/24/02 – 06/28/02 plant measurement data set and the 06/25/02 image data were performed. The Transformed Soil Adjusted Vegetation Index (TSAVI) and NIR correlation to the PGR rate generated a correlation of determination R2 of 0.26. However, when several different vegetation indices including Green NDVI (GNDVI), Red/Green, NDVI-Change, Uncalibrated-NDVI were aggregated together and correlated with the PGR rate, the R2 rose to 0.41. Regression equations between the imagery and plant measurements were used to generate rate recommendations for the application.

A discriminate analysis was performed on the 06/25/02 data set which led to the generation of a measurement called "Rate Index". The variables in the equation were :

Height = Plant height
Tnode = Total number of stem nodes
Internode = Length between 4th and 5th node

Three separate index equations were generated from a partitioning of the BASF Rate. The partitioning equations were :

If ("Basf Rate" == 0)
Rate Index = -17.13 + (-1.40)(Height) + (1.70)(Tnode) + 9.47(Internode)
If ("Basf Rate" > 0) or (Basf Rate < 5)
Rate Index = -37.46 + (-2.24)(Height) + (2.49)(Tnode) + 14.73(Internode)
If ("Basf Rate" > 5)
Rate Index = -71.67 + (-1.98)(Height) + (2.12)(Tnode) + 21.52(Internode)

The Transformed Soil Adjusted Vegetation Index (TSAVI) is a vegetation index that adjusts for the effects of bare soil in the background. The TSAVI and red band of the imagery were correlated to Rate Index with an R^2 of 0.26. The imagery was used to estimate the Rate Index. The scaled regression equation used to generate the Estimated Rate was :

Estimated Rate = -38.43 + 56.64(TSAVI) + .78(Red)

The field scouts recommended an application of 6 ounces per acre for the Blanket treatment strips. The Estimated Rate was scaled to the data range generated by the Pix Stick to provide a rate recommendation for each pixel in the field. The pixels in the site-specific treatment strips were placed into two application groupings; one getting 0 grams/hectare (0 ounce/acre) and the other getting 420 grams/hectare (6 ounce/acre). Thresholds were established on the Estimated Rates to group the site-specific pixels into these two groupings. Pixels with an Estimated Rate of less than 4.75 were put in the application group 1 (0 grams/hectare). Pixels with an Estimate Rate of greater than 4.75 were put in application group 2 (420 grams/hectare).

The pixels in the variable rate treatment strips were placed into three application groupings; one getting 0 grams/hectare (0 ounces/acre), another getting 280 grams/hectare (4 ounce/acre) and the other getting 420 grams/hectare (6 ounce/acre). Pixels with an Estimate Rate of less than 210 grams/hectare (3 ounce/acre) were put in the application group 1 (0 grams/hectare). Pixels with an Estimated Rate of between 210 grams/hectare (3 ounces/acre) and 385 grams/hectare (5.5 ounces/acre) was put in application group 2 (280 grams/hectare). Pixels with an Estimated Rate of greater then 385 grams/hectare (5.5 ounces/acre) were put in application group 3 (420 grams/hectare).

A 24 x 4.6 meter (80 x 15 foot) cell grid was established over the treatment strip groupings. All the cells in the 0% treatment strips were set to 0. All the cells in the 100% treatment strips were set to 420 grams/hectare (6 ounces/acre). Each cell in the SSPGR treatment strip was set to 0 grams/hectare (0 ounces/acre) if less than 20% of the pixels in the cell were in application group 1. The cell was set to 420 grams/hectare (6 ounces/acre) if more than 20% of the pixels in the cell were in application group 2. Each cell in the VRPGR treatment strip was set to 0 grams/hectare (0 ounces/acre) if the majority of the pixels in the cell were in application group 1. The cell was set to 280 grams/hectare (4 ounces/acre) if the majority of the pixels in the cell were in application group 2. The cell was set to 420 grams/hectare (6 ounces/acre) if the majority of the pixels in the cell were in application group 3.

The resulting cell grids established the spray pattern for the spray rig. The cell grid was converted to a shapefile and emailed to the Perthshire Farms. The shapefile was converted into a controller file for the AIM Navigational System. This prescription file was loaded into the spray rig controller. Pix Plus was mixed in the tank and applied to the field on 07/06/02. Since the liquid carrier and PGR were premixed, the rate changes were achieved by increasing and decreasing the rate of the liquid mix. The as-applied data that recorded the actual amount of chemical applied across the treatment strips was collected during the application. The composite data, TSAVI, prescription map and as-applied data are shown in Figure 4,5,6 and 7.

A similar process was performed on the 07/17/02 and 07/24/02 image data in order to provide a prescription in case the field scouts called for the second application in late July. In late July, the field scouts were calling for the second PGR application across the Perthshire Farms. Rain events during this time prevented the spray rig from being able to get into the field. Predicted rain events in the following week reduced expectation that the spray rig would be able to get into the field in the next two weeks. The window of time for applying PGR was passing. In order to apply PGR within the application timing window, the Perthshire production team made a decision to blanket spray PGR on all the Perthshire Farm fields. Field T167-18, the PGR experiment field, was blanket sprayed with 10 ounces/acre of Pix Plus on 07/26/02.

The blanket application of PGR on the experiment field modified the experiment plan. Even though the blanket application occurred, it resulted in a uniform application across each of the treatment strips. This application concluded the PGR application for Perthshire Farms for the growing season.

The experiment design called for PGR applications in the amount of 0 grams/hectare (0 ounces/acre) on the 0% treatment strips, 1121 grams/hectare (16 ounces/acre) on the 100% treatment strips, 0 to 1121 grams/hectare (0 to 16 ounces/acre) on the SSPGR treatment strips and 0 to 1121 grams/hectare (0 to 16 ounces/acre) on the VRPGR treatment strips. In actuality, the 0% treatment strips received 701 grams/hectare (10 ounces/acre) because of the blanket application. Also, the SSPGR and VRPGR treatment strips received 701 to 1121 grams/hectare (10 to 16 ounces/acre). The final as-applied map added 701 grams/hectare (10 ounce/acre) more to all treatment strips. The discussion, tables and graphs that will be included later in this report will refer to the 0PGR strips as the "Blanket Low" strips and the 100PGR strips as the "Blanket High" strips. These cumulative season prescription map and as-applied data sets are shown in Figure 8 and 9.

Correlations were generated between plant parameters and imagery. The dates for the 10 data acquisitions were shown in Table 1. The raw data from these dates were calibrated. Although the imagery was collected on one date, the collection time for the plant measurements was influenced by rain events. In general the plant measurements were collected from the 112 sample points over a 2 to 4 day period.

Eight data sets pairings of imagery and plant data were established across the season starting from the 06/25/02. Vegetation indices were generated from both the calibrated and uncalibrated data. The vegetation indexes generated were TSAVI, NDVI (Calibrated), Green NDVI (Calibrated), NDVI Change, Green NDVI Change, NDVI (Uncalibrated) and Green NDVI (Uncalibrated).

All the correlations had significant relationship at an alpha level of 0.01. The R^2 of the correlations between the plant parameters and vegetation indices are shown in Table 2. The R^2 values generated for the correlations of NDVI Change with each of the plant parameters were less than 0.05. The R^2 values generated for the correlations of Green NDVI Change for all plant parameters were slightly higher than the NDVI Change R^2 values, but still very small. Since these values are so low they are not represented in the table.

The plant height variance was tested to determine the plant canopy management effectiveness of the PGR applications in the treatments. The plant height variance for the four treatments was generated (Table 3). The Blanket Low treatments had a plant height variance of 1.85 meters (72.86 inches), which was the highest variance out of the four treatment types. Results of statistical analysis show that there was no difference in the variance of the plant heights across the treatment strips (alpha = .05).

About a quarter of the PGR experiment field was harvested on 10/03/2002. On 10/04/2002 Hurricane Lili came onshore and ran through the Mississippi Delta. The harvest operations were halted as the rain began to impact the soil. All harvesting stopped for about 2 weeks in order to let the soil dry out. The rest of the PGR experiment field was harvested on 10/15/2002 – 10/16/2002.

Cotton yield measurements were obtained using Case-IH six row cotton pickers equipped with an Ag Leader PF3000 Pro (Ag Leader Technology, Ames, IA) commercial yield sensing system and DGPS receiver. Data were collected at 2-second intervals and written to a PCMCIA card located on the yield monitor. Yield monitor calibration was accomplished using a boll buggy equipped with an electronic scale. Randomly selected loads were weighed and compared with the yield monitor load weight. If necessary, correction factors were then applied to the yield monitor.

After harvest, the yield data files were downloaded from the PCMCIA cards and exported to comma-delimited ASCII files for further processing. Each data file was converted to an ESRI shapefile and edited to remove points logged when the picker had stopped and/or momentarily reversed its direction of travel (i.e., due to plugging). After editing was completed, the shapefile was saved and exported as a comma-delimited ASCII file.

Next, the yield data was processed with Microsoft Visual Basic (Microsoft Corporation, Redmond, Washington) using algorithms similar to those described by Birrell et al. (1996). Observations with yields below 25 lbs/acre and above 12000 lbs/acre were removed as well as observations collected when the picker was traveling at speeds less than 0.5 miles/hour. At the same time, geographic coordinates (longitude, latitude) were converted to Universal Transverse Mercator (UTM) coordinates.

The 20x60 meter area around each sample point was averaged to produce a yield estimate for the sample point. Yield from the 7 sample point locations for each strip were averaged to give a yield estimate in lbs/acre for that treatment strip (Table 4 and Figure 10). The statistical analysis shows that there was no significant yield difference between any of the treatments (alpha = 0.05). This shows the precision application techniques maintained yield when compared to the traditional blanket method.

Cotton prices vary across different staple lengths and grades. The cotton price on the 11/07/2002 USDA AMS Market Reports shows the price for cotton in the South Delta to be in the range of 19 to 22 cents/kilogram (42 to 49 cents/pound). For the net profit analysis the cost of 19 cents/kilograms (42.23 cents/pound) was used. This is the price for cotton with a staple length of 33 and a rating of 51-5. A sampling of agriculture chemical stores in the Cleveland, Mississippi area was used to generate the cost of Pix Plus at $246 per liter (50 cents per ounce).

The net profit was calculated as :

"Net Profit" = ("Price of Cotton" * "Yield") – ("Amount of Pix Applied" * "Cost of Pix")

The actual lint yield per treatment strip was not available. The lint yield was calculated as 35% of the seed cotton yields. Net profit values were generated for each treatment type. There was no statistical difference in net profits between any of the experiment treatments (alpha .05; Table 5).

Significant reduction in chemical can translate into a reduction in the cost of application. An economic analysis was performed under the direction of the MSU Agriculture Economics Department. The economic analysis compares the cost of traditional (blanket) applications to the cost of precision application methods. This cost included equipment, chemical, human resource and imagery costs. It computed the total cost of application for both the precision application methods and the traditional blanket method. The SSPGR method had a reduction of 21.5% over the 1121 grams/hectare (16 ounce/acre) blanket spray. The VRPGR method had a reduction of 22.3% over the 1121 grams/hectare (16 ounce/acre) blanket spray. Since the chemical reduction for the SSPGR and VRPGR strips were almost identical, they were grouped together as the "precision application method" for this economic analysis.

The costs for blanket application include the cost of the spraying equipment and human resources to operate the equipment. For the precision application method, the additional costs include agriculture consultants, remote sensing data collection, and processing. The comparison provides a percentage cost savings of precision application method over blanket PGR.

The costs associated with implementing the conventional (Blanket) method include Pix Plus® chemical and application. The PGR application costs cover the cost of the spray rig with the 27 meter (90 foot) boom, the fuel consumption, diesel fuel cost, salvage, repair, maintenance costs, performance rates, and driver costs. All calculations assumed a fully utilized machine.

The precision application method has some additional costs for spray rig equipment enhancements, remote sensing data acquisition and value added data processing, prescription generation, and management by a service consultant or private precision farming specialist. The additional spray rig costs include the cost of the ruggedized notebook computer, spray controller and miscellaneous GPS equipment. This analysis assumes there are 3 data acquisitions performed in order to provide 3 vegetation index scout maps during the June/July time period.

The cost of $2.47/hectare was used as the raw data collection cost in this analysis. It was assumed that a data service company can provide the data in a band-to-band registered and georeferenced format. The value added processing cost was estimated at $0.30/hectare. This cost includes estimations for downloading data, masking fields, generation of vegetation index image maps, materials, and data grid generation. The prescription generation costs include costs for prescription creation, loading the prescription into the spray rig, and downloading and archiving as applied data. These costs were calculated as "loaded costs" and assume overhead and fringe.

Assuming a blanket application of 1121 grams/hectare (16 ounces/acre), the cost of Pix Plus® is $19.75 per hectare. The Pix Plus® cost is the same for the precision application and conventional methods. The PGR application cost is $3.23 per hectare for the conventional method and $3.83 per hectare for precision application method. The remote sensing data collection and processing costs for the precision application method are $2.77 per hectare. The service consultant costs for the precision application method are $0.41 per hectare. This results in a total of $22.99 per hectare cost for the conventional application and $26.75 per hectare cost for the SSPGR application. These costs are presented in Table 6.

During this study the amount of reduction of the SSPGR over the blanket application was 21%. Further research needs to be performed to make recommendations of what percent of the field should be treated. The percentage of chemical reduction is critical to the economic analysis in that the chemical reduction value used has a big impact on the final percent savings amount.

The costs associated with the conventional and precision application methods are shown in Tables 7, 8 and Figures 11 and 12. The columns show the information for the conventional and SVPGR methods and also the cost savings. The rows show the cost per hectare; number of hectares, total cost and percentage cost as compared to the conventional method. They show that if the PGR application is reduced by 22%, the precision application method has a cost savings of 9% over the conventional method. Assuming an application chemical reduction of 22% for the 30 hectare (75 acres) in the PGR research field, the cost to perform the PGR application using the conventional method would be $697.75; the cost of the precision application method would be $633.25; and the cost savings would be $64.49. When extrapolated to 4000 hectares (9884 acres), the cost of the conventional method would be $91,960; the cost of the precision application method would be $83,460; and the 9% cost savings would be $8,500.

The economic analysis calculates that a 14% reduction in Pix Plus® needs to be realized before the precision application methods begin to save money. Assuming the amount of PGR saved by utilizing the precision application techniques is 22%, after integrating the application costs, data collection costs and prescription management costs, the cost of the precision application method as compared to the conventional method is reduced by 9%. This demonstrates that using precision application methods instead of the traditional blanket application method can reduce the cost of PGR applications to the cotton producer.

Conclusions

There were significant relationships between plant parameters and image data. All the tests performed were significant at an alpha level of 0.05. Plant height measurements had the highest R^2 values. The plant height correlation had a R^2 value of .47 with TSAVI, a R^2 of .44 with NDVI and a R^2 of .55 with Green NDVI (Uncalibrated). The length of the top 5 nodes had a R^2 of .33 with TSAVI, a R^2 of .36 with NDVI (uncalibrated) and a R^2 of .40 with Green NDVI (uncalibrated).

Image data was used in the prescription generation process. The resulting yield for the four treatments were not significantly different. Therefore the yield was maintained with the precision application methods. This indicates that while the plant parameter to imagery correlations may not be high, the prescriptions generated from the imagery were still effective.

There was no significant difference in the variance of the plant height across the treatments. This indicates that the precision application methods did at least as well as the two blanket treatments at managing crop canopy.

An economic analysis was done to determine the amount of chemical reduction that would be required to save money by using precision application methods. The economic analysis shows that a 14% reduction in PGR as being the breakpoint between saving or losing money with the precision application methods. The economic analysis of the precision application methods showed that a Pix Plus® reduction of 22% results in 9% reduction in the cost of applying PGR.

The two precision application methods did not perform significantly different. The yields were very similar. There was not much difference in the reduction in PGR application. The site-specific application calls for only two application rates; on or off. To determine whether a pixel should be "on" or "off", only one threshold on the vegetation index needs to be established. This threshold simply specifies whether the spray nozzle should be open or closed.

The variable rate application is more complicated than the site-specific application. More than one threshold on the vegetation index needs to be established. Algorithms for determining these thresholds are not well established. This study used only three rates in the variable rate strips. However, if additional rates are added, the complexity of deciding where to set vegetation index thresholds is increased. This study indicates that the site-specific application is just as effective as the variable rate application. As this method moves to a large scale demonstration project site-specific applications should be used over variable rate applications. Research should continue to test if there are vegetation index thresholding techniques that would increase the effectiveness of the variable rate application approach.

Future Work Recommendations

Next year the PGR research should be performed in a large field demonstration. The purpose of this demonstration would be to overcome any logistical problems in the implementation of PGR precision application methods and to investigate producer interest in this technique. In addition, the experiment from this year should be replicated. Additional treatments that generate prescriptions from several different vegetation index maps should be used. An attempt should be made to simplify the prescription generation process. Better understanding of simplified thresholding techniques of the vegetation index need to be understood in order to supplement the large field demonstration. This understanding will help the following years expansion of the large field demonstration.

Central to the success of a large field demonstration is the ability to perform the precision application technique from the air. This year the experiment suffered from rain events that prevented the spray rig from getting into the field. This resulted in a blanket application of PGR from the air. Rain events can prevent ground based chemical applications from occuring. In order to increase the usage of precision application methods, aircraft equipment need to be converted to accommodate precision application methods. Next year the possibility of using an aerial applicator for the precision application technique will be investigated.

Acknowledgements

The ITD team would like to acknowledge the following persons and companies that have contributed to the design, implementation, and analysis of this experiment. Without the gracious support of these individuals, this experiment would not have been possible.

The NASA ESA Directorate Program, Mr. Kenneth Hood, Hood family and the Perthshire Farms staff, Johnny Freeman, Doug Cauthen, Russell Cauthen, Dr. Jeff Willers, Dr. David Laughlin, Dr. Greg Carter, Geotek Management Services, Mid-South Ag Co., CASE-IH, AIM.

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Table 1. RDACS Flight Dates.

Flight	**1**	**2**	**3**	**4**	**5**
Date	06/13/02	06/18/02	06/25/02	07/02/02	07/08/02

Flight	**6**	**7**	**8**	**9**	**10**
Date	07/17/02	07/24/02	07/30/02	08/06/02	08/27/02

Table 2. R^2 Values of Imagery / Plant Parameters (all correlation were significant at alpha level of .01).

Plant Parameter	**TSAVI**	**NDVI (Calibrated)**	**NDVI (Uncalibrated)**	**Green NDVI (Calibrated)**	**Green NDVI (Uncalibrated)**
Plant Height	.47	.44	.44	.40	.55
5^{th} Internode Length	.18	.17	.16	.17	.25
Average Internode Length	.33	.33	.36	.33	.40
Length of Top 5 Nodes	.33	.33	.36	.33	.40
Number of Nodes	.13	.17	.19	.17	.14

Table 3. Plant Height Variance By Treatment.

Treatment	Plant Height (meters)			df
	Mean	Std	Variance	
Blanket Low	0.55	0.22	0.0470	1015
Blanket High	0.56	0.20	0.0400	1015
SSPGR	0.58	0.21	0.0443	1015
VRPGR	0.55	0.21	0.0429	1030
Average	0.71		0.0436	

Table 4. Mean Yield for Treatment Strips.

Treatment Strip	Seed Cotton Yield (lbs/ac)
Blanket Low	2445
Blanket High	2627
SSPGR (Off/On)	2618
VRPGR (Off/Middle/High)	2642

Table 5. Net Profit Averages of Treatment Strips.

Treatment	PGR Applied (kg)	Lint Yield (kg/ha)	Net Profit (dollars)
Blanket Low	21	806	$1,182
Blanket High	34	896	$946
SSPGR	26	891	$1,168
VRPGR	26	882	$1,156

Table 6. Blanket vs Precision Application PGR Summary Costs.

Item	Conventional $/ha	Precision $/ha
Plant Growth Regulator material (Pix) (1121g/ha)	$19.75	$19.75
Plant Growth Regulator application	$ 3.23	$ 3.83
Imagery	$ 0	$ 2.77
Service consultant	$ 0	$ 0.41
Total	$22.99	$26.75

Table 7. Cost Analysis for 22% PGR Reduction.

	Conventional	Precision	Savings
Cost/Ha	$ 22.99	$ 26.75	-3.76
Ha	30.35	23.67	6.68
Total Cost	$697.75	$633.25	$64.49
% Cost	100	91	9

Table 8. Cost Analysis Extrapolated to 4000 Hectares.

	Conventional	Precision	Savings
Cost/Ha	$22.99	$26.75	-3.76
Ha	4,000	3,120	880
Total Cost	$91,960	$83,460	$8,500
% Cost	100	91	9

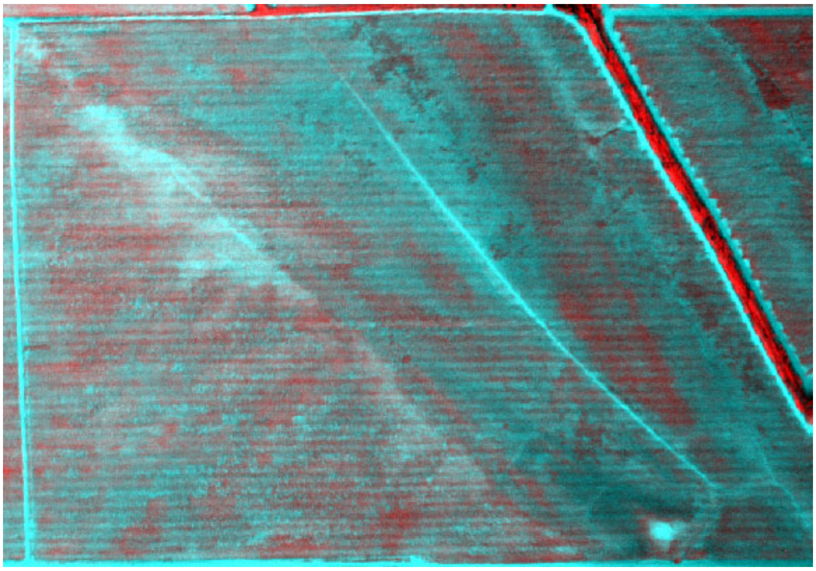

Figure 1. False Color Composite of Perthshire Farms Field T167-18 from July 8, 2002 Data.

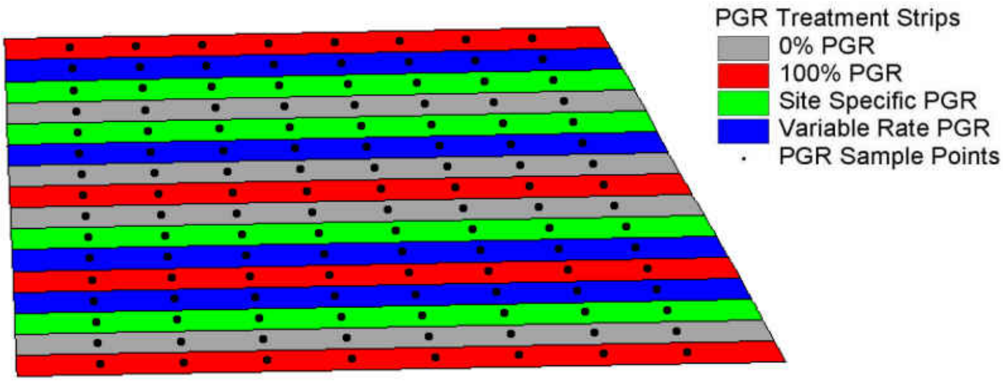

Figure 2. Treatment Strips with Sample Points.

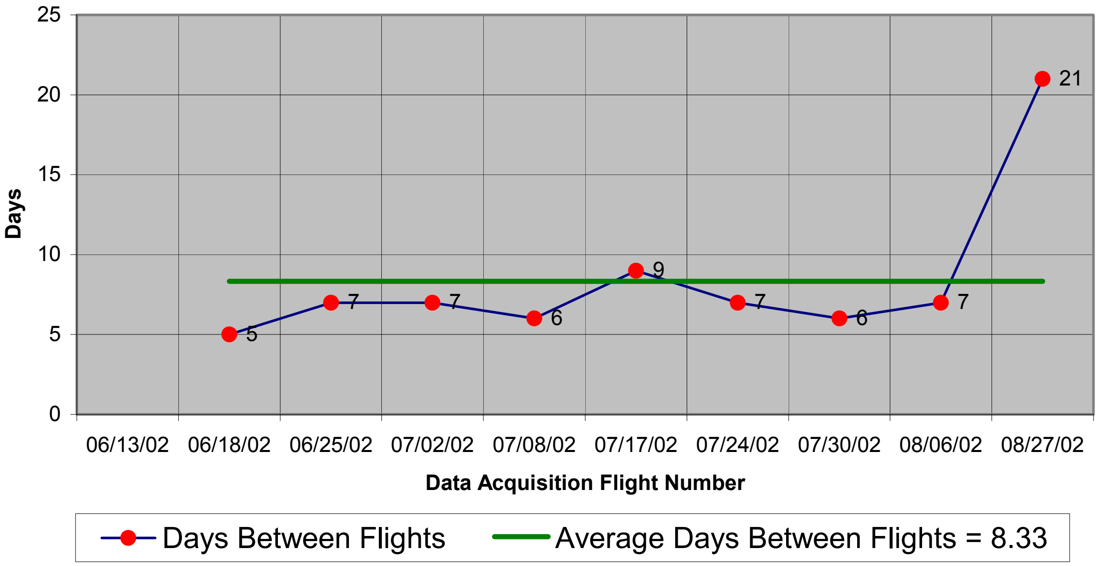

Figure 3. Days Between Data Acquisition Flights.

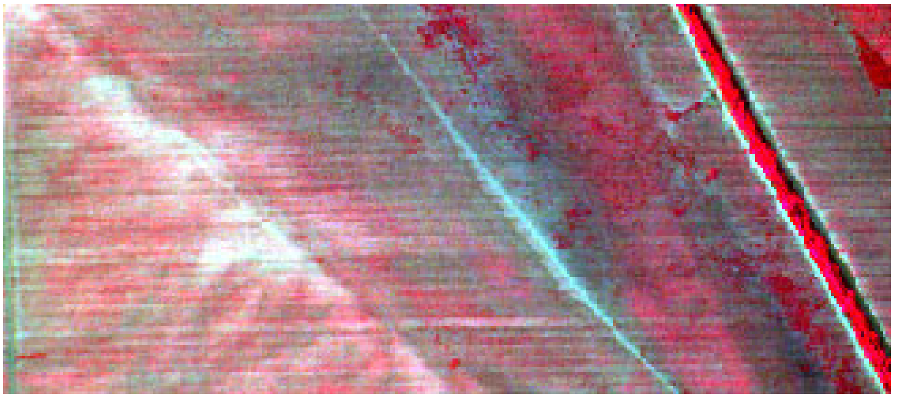

Figure 4. 06/25/02 Raw Data.

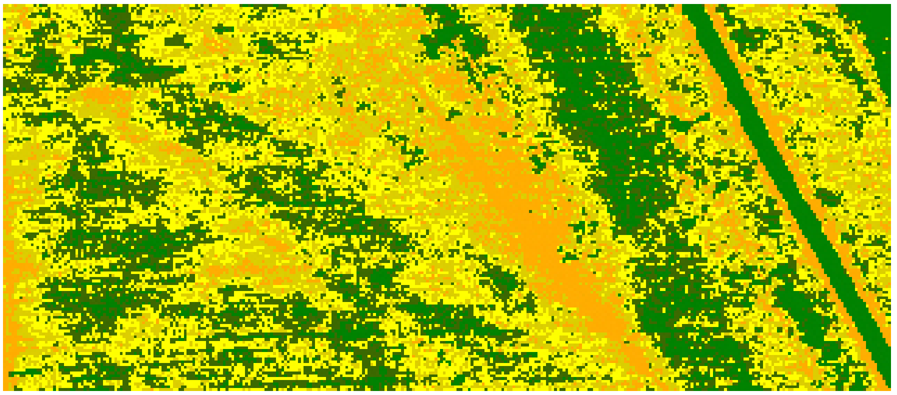

Figure 5. 06/25/02 TSAVI.

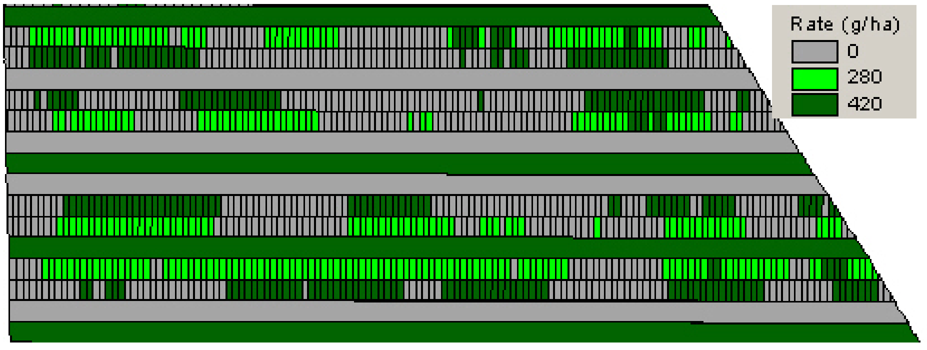

Figure 6. 06/25/02 Prescription.

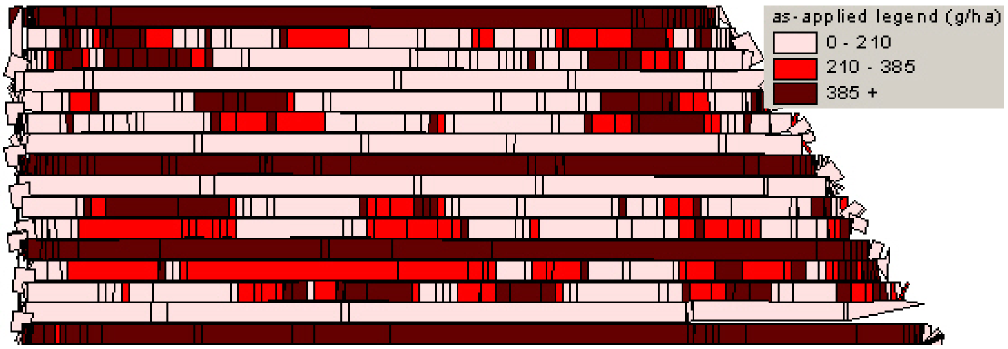

Figure 7. 07/06/02 As-Applied Data.

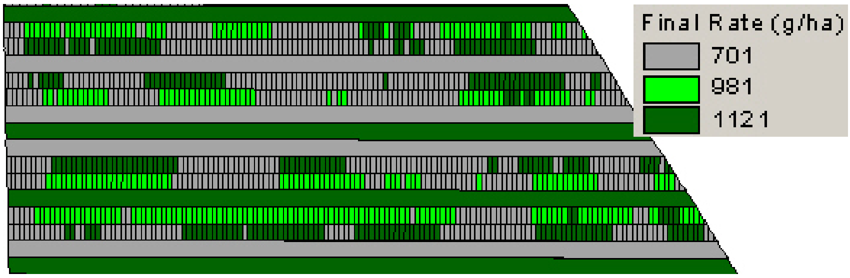

Figure 8. Cumulative Season Prescription.

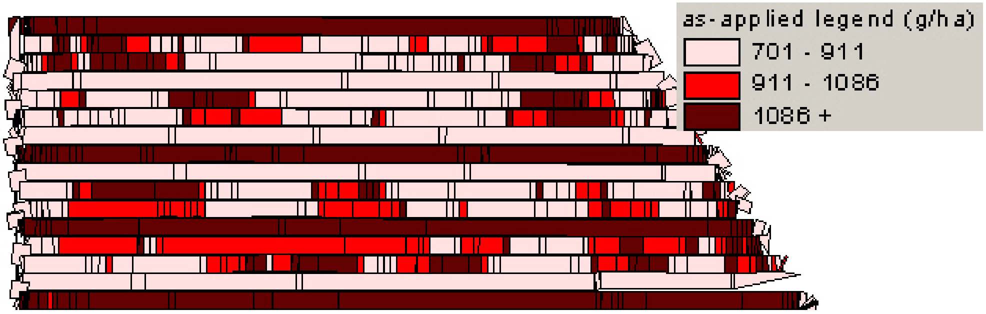

Figure 9. Cumulative Season As-Applied Data.

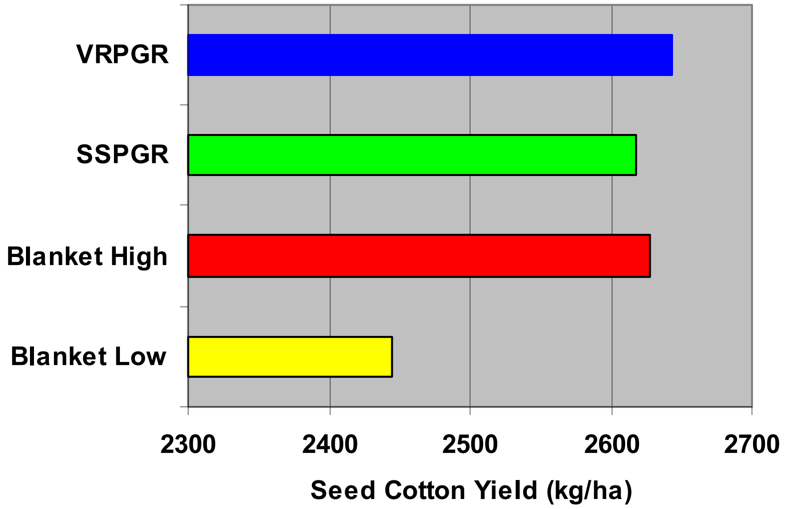

Figure 10. Mean Yield per Treatment.

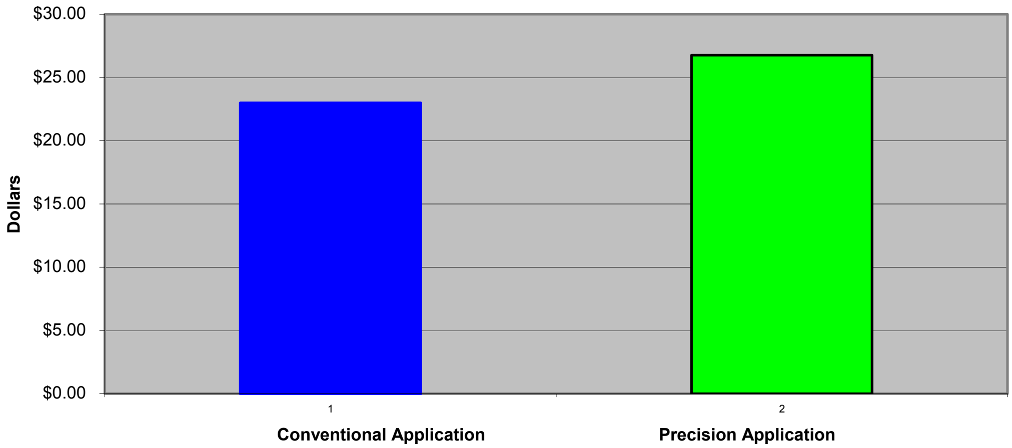

Figure 11. Conventional and SVPGR Cost/Acre.

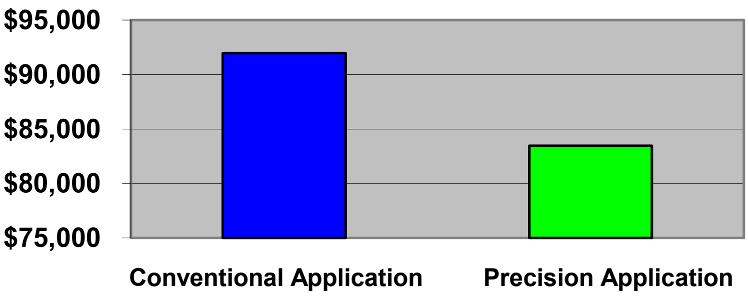

Figure 12. Costs Extrapolated to 4000 Hectare Field.